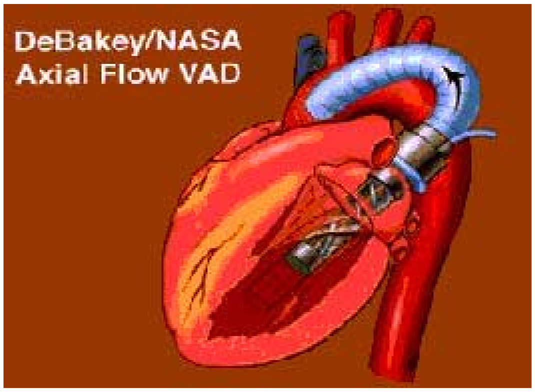
I Have The Heart Of A Rocket

The last place you'd expect to find part of a rocket engine is attached to the human heart.

Rocket engines are notoriously fickle and demand pampering to pump strange fluids like liquid hydrogen for just a few minutes of life. The heart is a durable device, changing its output to meet new demands and enduring a range of stresses for decades.



Merging the two was the brainchild of a NASA engineer who himself had to wait for a transplant in 1984. Why not borrow some space technology, he asked his doctor, to give the heart a boost for a few months?

On paper it looked great. In clinical trials with animals, it only worked two days. Longer life in the pump was needed to give longer life to patients. Such differences between plan and test are not unusual in engineering development work. So the team designing the assist pump turned to the Numerical Aerospace Simulation (NAS) Systems Division at NASA's Ames Research Center in Mountain View, CA.

"Using CFD we can experiment with different design configurations," said Dochan Kwak, Chief of Applications Branch in NAS Systems Division, before committing to building one for tests. Among other tasks handled by the NAS are simulations of refinements to the Shuttle Main Engine.

NAS specializes in computational fluid dynamics (CFD), the science of using computers to simulate the movement of liquids and gases through complex paths.

"Moving blood is different from moving liquid hydrogen or water," Kwak said. But it can be simulated in computers just as liquid hydrogen can.

The heart pump project started in 1984 after David Saucier of NASA's Johnson Space Center got his transplant following a wait of several months. He approached his doctor, Dr. Michael DeBakey, a pioneer in heart transplants, about adapting axial pump designs for use in heart assist pumps.

NASA's Johnson Space Center, DeBakey's team at Baylor College, and biomedical experts at MicroMed Technology, worked together to develop a ventricular assist device (VAD).

The human heart (like those of all mammals and birds) has four chambers. The right auricle and ventricle receive blood from the body and pump it into the lungs to exchange carbon dioxide for oxygen. The left auricle and ventricle receive blood from the lungs and pump it out to the body.

Because it has to push blood out to the entire body, the left ventricle is under the greatest strain and often fails first. The VAD was designed to reduce the left ventricle's load while keeping blood flowing to the rest of the body.

The way the VAD snakes around the heart resembles the plumbing encircles the Space Shuttle Main Engine. A titanium cannula directs blood from the lower tip of the left ventricle into the VAD, and a plastic cannula directs from the pump to the aorta, the main artery leaving the top of the heart. Curved blades on the rotating impeller spin at 5,000 to 12,000 rotations per minute (rpm), up to the same speed as the low-pressure fuel pump on the Space Shuttle Main Engine.

The pump is 76 mm (3 in) long and weighs just 90 grams (4 oz). It is powered by two batteries carried in a pack carried at the patient's belt. The internal battery has a two-hour life, enabling patients to take a shower, and can be charged by induction through the skin.

The "heart" of the heart pump is an enclosed spinning impeller that pushes blood through the pipes. This is where NAS was needed to refine the design.

Kwak and Cetin Kiris, principal research scientist in the project, faced two significant problems to overcome in refining the pump.

"In natural heart, flow is laminar," or smooth, explained Cetin Kiris, Kwak's partner in the project. "In the pump we had to deal with turbulent flow." This can elongate and rupture the red corpuscles. So can prolonged contact with artificial surfaces as the corpuscles sweep by.

"The second problem is thrombosis," Kiris continued. "Blood clots when it gets into stagnant regions." If a thrombosis breaks lose, it can lodge in the lungs or heart and kill.

So the challenge was to design the pump to provide a smooth, steady flow that would not damage red cells or give them a chance to clot.

"We want the device to propel the blood very smoothly," Kiris continued. "We don't want any stagnant regions."

They added an inducer that raised the blood pressure going into the pump and made the flow more efficient. They tapered and reshaped the cavity to accelerate the flow and to wash the walls better so cells could not linger and clot.

The changes reduced hemolysis -- corpuscle destruction -- by 90 percent. But there was a problem with clotting in the narrow gap between the spinning impeller and the stator, a fixed component that holds the impeller in place.

All previous efforts had been to narrow the gap between impeller and stator so red cells could not get enmeshed in the parts. Those didn't work, so Kwak and Kiris did the reverse: they opened the gap and thus improved the flow to move the corpuscles through quickly.

"By design changes and optimization and blade shape changes, we were able to make the pump operational," Kwak said.

Pump life in clinical trials was extended to an impressive 120 days. In practice, it has operated for five to six months, thus giving patients a bigger window of safety while they wait for a donor.

For now, the DeBakey VAD, as it is now called, is an experimental device, according to the U.S. Food and Drug Administration. It has done well in European trials that started in late 1998 -- one of the first patients was able to go home for Christmas -- and in U.S. trials since June 2000. MicroMed earned exclusive patent rights to market the DeBakey VAD. In 1999 the device was recognized by the U.S. Space Federation's Space Technology Hall of Fame. Kiris and Kwak are listed as co-inventors with the teams at NASA/Johnson, MicroMed, and Baylor.

Kwak and Kiris aren't finished with the VAD yet.

"It's not simple to simulate and find an optimum patient," Kwak said. "Each patient has a different chest cavity and we have to work on different flow angles and cross-section optimizations" for the two elbow-shaped cannulas that lead into and from the VAD.

They are also applying their CFD tools to modeling the flow of blood at bifurcations, points where an artery divides, like the descending aorta splitting for the left and right legs. Why does cholesterol sometimes form on one side and not the other? Or, what are the dynamics of blood flowing in an aneurysm, a dangerous ballooning of a vessel that can rupture and kill?

Kwak and Kiris would also like to enhance the VAD so it adapts to changes in a patient's activities, from sleep to moderate exertion like climbing stairs.

"We're doing this because we like it," Kwak said. "We love to do this."

Courtesy of NASA'S
Aerospace Technology Enterprise

Article Published by NASAexplores: February 8, 2001